J/ψ and ψ(2S) production in Pb-Pb collisions with the ALICE Muon Spectrometer at the LHC

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Abstract

Charmonium states are considered important signatures of the strongly interacting medium created in heavy-ion collisions. In the ALICE experiment, these probes can be investigated in the $\mu^+\mu^-$ decay channel, in the forward rapidity region (2.5< y <4) down to zero transverse momentum. Results on charmonia production in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV are presented. The centrality and transverse momentum dependence of the inclusive J/ψ nuclear modification factor are shown and compared with theoretical models. Finally, first ALICE results on the ψ(2S) production in Pb-Pb collisions are also discussed.

The ALICE experiment at the Large Hadron Collider (LHC) is designed to study the formation of the strongly interacting matter in high energy heavy-ion collisions. Among the probes of the expected phase transition between hadronic and deconfined matter, a relevant role is played by quarkonium states. In particular, according to the color-screening model [1], the in-medium dissociation probability of such states should provide an estimate of the initial temperature reached in the collisions. Studies performed in the last twenty years at the SPS and RHIC facilities, at $\sqrt{s_{NN}}$=17 and 200 GeV respectively, have, indeed, shown a reduction of the J/ψ production yield beyond the expectations due to the cold nuclear matter effects (i.e shadowing and nuclear absorption). In spite of the very different center of mass energy, the amount of suppression observed by SPS and RHIC experiments is similar. Furthermore at RHIC a stronger J/ψ suppression has been measured at forward with respect to mid-rapidity. These observations suggest the existence of an additional J/ψ production mechanism, which sets in when higher $\sqrt{s_{NN}}$ are reached. This mechanism, based on the combination of initially uncorrelated c and $\bar{c}$ pairs [2, 3, 4], can counteract the quarkonium suppression in the QGP. Therefore, the measurement of charmonium production is especially promising at the LHC, where the high-energy density of the medium and the large number of $c\bar{c}$ pairs produced in central Pb-Pb collisions should help to disentangle suppression and regeneration scenarios.

The ALICE experiment [5] studies quarkonium production in the $\mu^+\mu^-$ decay channel in the rapidity region $2.5 < y < 4$ and in the e^+e^- decay channel at $|y| < 0.9$ [6]. In this paper, we present quarkonium measurement at forward y, while results obtained at mid-rapidity are discussed in [7].

Muons are identified and tracked in a Muon Spectrometer equipped with a dipole magnet, a set of absorbers, five tracking chambers and a trigger system. The pixel layers of the Inner

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[1]A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

Tracking System allow the vertex determination, while forward detectors such as the VZERO scintillators are used for triggering purposes. The VZERO is also used to determine the centrality of the collisions, through a fit, based on a Glauber model, to its signal amplitude [8]. Results presented in the following are based on a sample of dimuon triggered events corresponding to an integrated luminosity $L \sim 70 \ \mu b^{-1}$, collected during the 2011 Pb-Pb data taking. A clean data sample is obtained applying quality cuts to the muon tracks. These cuts eliminate mainly tracks hitting the edges of the spectrometer's acceptance or crossing the thicker part of the beam shield. Furthermore, to remove hadrons produced in the front absorber, tracks reconstructed in the tracking chambers are required to match hits in the trigger planes.

The in-medium modification of the J/ψ production is quantified through the nuclear modification factor (R_{AA}), defined as the ratio of the J/ψ yield measured in Pb-Pb collisions and the expected yield obtained scaling the pp J/ψ production cross section by the number of binary nucleon-nucleon collisions. The J/ψ yield is extracted by fitting the opposite sign invariant mass spectrum with an extended Crystal-Ball function (CB2), which allows the inclusion of non-gaussian tails on both sides of the J/ψ pole. The mass position and the width of the CB2 are kept as free parameters in the fit, while the tails are tuned on a MC where a J/ψ signal is embedded into real events. The background contribution under the J/ψ is described by a gaussian function with a mass-dependent width. Alternatively, an event mixing procedure has been applied, to subtract the background contribution, before fitting the signal. The raw J/ψ yield is determined as the average of the results obtained with the two approaches, including also some modifications of the fitting procedure (e.g. different CB2 sets of tails or alternative fitting functions). The corresponding systematic uncertainties on the signal extraction are defined as the r.m.s. of these results. Details on the analysis are given in [9]. The total number of J/ψ in the kinematic region 0< p_T <8 GeV/c, 2.5< y <4 and in the centrality range 0-90% amounts to ~40000. The high statistics collected in 2011 allows, therefore, a differential study of the J/ψ production yield, as a function of centrality, y and p_T. The procedure described above is applied in each kinematic bin under study. To evaluate the R_{AA} the J/ψ yield is divided by the acceptance × efficiency ($A \times \epsilon$), computed by embedding generated J/ψ particles into real events. The average $A \times \epsilon$ is ~14%, with an 8% decrease from peripheral to central collisions. Finally, the J/ψ yield measured in Pb-Pb collisions, in each kinematic bin, is normalized to the corresponding inclusive J/ψ cross section measured in pp collisions at the same energy [10]. Systematic uncertainties on the R_{AA} depend on the kinematic range under study. The main source is due to the pp reference (~9%), while other contributions, related, for example, to the choice of the MC inputs, to the uncertainty on the trigger, tracking and matching efficiency and to the signal extraction amount to less than 6-7% each. The inclusive R_{AA} integrated over centrality, p_T and y is $R_{AA}^{0-90\%} = 0.497 \pm 0.006(stat) \pm 0.078(syst)$, exhibiting a clear J/$\psi$ suppression. In our y and p_T domain, the contribution from beauty hadron feed-down to the inclusive J/ψ yield amounts to ~10%, having a negligible effect on the R_{AA} measurement. The centrality dependence of the R_{AA}, integrated over p_T and y is shown in Fig.1 (left). The pattern observed by ALICE presents a weaker centrality dependence and a smaller suppression for central collisions with respect to PHENIX results [11], suggesting a different interplay, at the two energies, of suppression and regeneration mechanisms. Models including a large fraction of J/ψ produced from pair (re)combination [12, 13, 14] or all J/ψ produced at hadronization [3] can reasonably describe the measured R_{AA}. The (re)combination contribution is expected to be dominant, especially in central collisions, at low p_T, while it becomes negligible as the J/ψ p_T increases. This behaviour can be investigated by further studying the R_{AA} p_T dependence in centrality bins, as shown in Fig.1 (right). While for the peripheral bin (40-90%) the p_T dependence is negligible, in the most central bin (0-20%) the suppression increases by ~60%
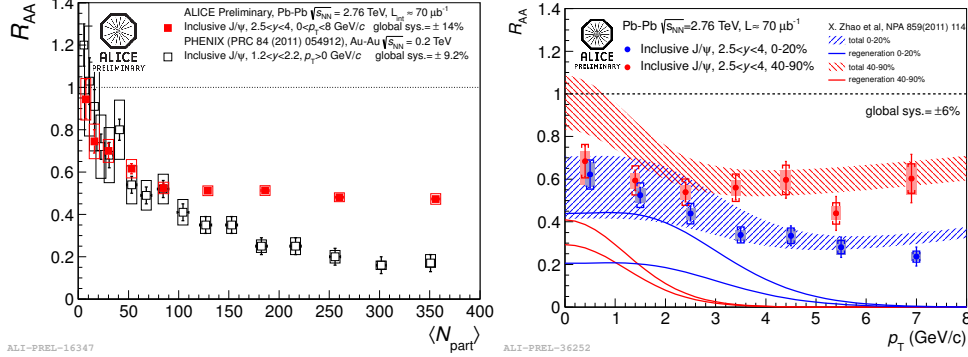
Figure 1: Left: the J/ψ R_{AA} is shown as a function of N_{part} and compared to the PHENIX result. Statistical errors are shown as lines, while systematic uncertainties are shown as boxes around the points. Right: the R_{AA} p_T dependence is shown for two centrality classes and compared to a theoretical model [12]. In this case, systematic uncertainties are split between uncorrelated and partially correlated components, shown, respectively, as boxes and brackets around the points. The theoretical bands represent the uncertainty on the calculation due to different shadowing assumptions. Global systematic uncertainties are listed in the legend.

moving towards low p_T. Models including a p_T-dependent contribution from (re)combination which amounts, at low p_T, to 60% in central and 30% in peripheral collisions [12, 13], provide a reasonable description of the data.

Further hints on the J/ψ behaviour as a function of p_T can be inferred from the centrality evolution of the $\langle p_T \rangle$, extracted from a fit to the $d^2N_{J/\psi}/dydp_T$ distributions. As presented in Fig.2 (left), $\langle p_T \rangle$ decreases towards central collisions, pointing to a smaller suppression of low p_T J/ψ. On the contrary, PHENIX results [11, 15, 16] show a different trend, with a $\langle p_T \rangle$ increasing with centrality, confirming the different J/ψ behaviour, versus $\sqrt{s}$, already shown in Fig.1(left).

Further insight on charmonium production in Pb-Pb collisions can be achieved by comparing the ψ(2S) yield to that of the J/ψ. Results are presented as a double ratio of the ψ(2S) to J/ψ yields in Pb-Pb and in pp collisions as a function of centrality and in two p_T classes (0 < p_T < 3 GeV/c and 3 < p_T < 8 GeV/c). Signals are extracted with the aforementioned fitting procedure, keeping the ψ(2S) mass position and width fixed relative to the J/ψ ones, and then corrected for the corresponding $A \times \epsilon$. For 0-20% centrality, the very low signal over background ratio (S/B) prevents the extraction of the ψ(2S) yield at low p_T, while in the higher p_T bin (S/B~0.01) only an upper limit can be evaluated. Since many of the systematic uncertainties cancel out in the double ratio, the main contribution to the systematic error is due the signal extraction, being of the order of ~15-60% depending on the kinematic bin. The pp reference has been evaluated at $\sqrt{s}$=7 TeV. Therefore, we have included a ~15% contribution to the systematic uncertainty to take into account a possible $\sqrt{s}$-dependence of the ψ(2S)/J/ψ ratio evaluated by comparing CDF [17], LHCb [18] and CMS [19] results. Double ratio results are shown in Fig.2 (right). The large statistics and systematic uncertainties preclude the drawing of strong conclusions on the ψ(2S) behavior. A significant enhancement in the double ratio for more central collisions is not visible in the ALICE data.

We have presented ALICE results on the J/ψ R_{AA} as a function of centrality and p_T in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV, at forward rapidity. The R_{AA} shows a clear reduction of the J/ψ yield, with a negligible centrality dependence and a strong p_T dependence, especially in central
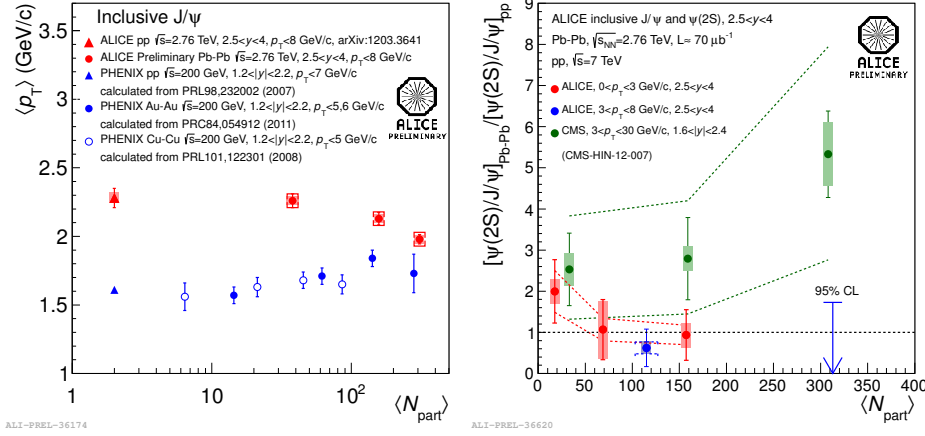
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Figure 2: Left: the J/ψ ⟨p_T⟩ is shown as a function of N_{part} and is compared with results from the PHENIX experiment. ALICE statistical errors are shown as lines, while uncorrelated and partially correlated systematic uncertainties are shown, respectively, as boxes and brackets around the points. Right: the double ratio ψ(2S)/J/ψ in Pb-Pb and pp is shown versus centrality and compared to CMS values [20]. Statistical errors are shown as lines, while systematic uncertainties are shown as filled boxes. The statistical and systematic uncertainties on the pp reference is shown as dotted lines.

collisions. The J/ψ behaviour presents different features with respect to the one previously observed by lower energy experiments. These features can be qualitatively described by theoretical models which include (re)combination as an additional mechanism for J/ψ production. Further insight in the understanding ot the J/ψ behaviour still needs a precise knowledge of the cold nuclear matter effects, which will be studied in the incoming p-A data taking.

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